Fiber Optic Current Measurements Using Faraday Rotation Diagnostics

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It is often necessary to measure extremely large pulsed electric currents when conducting pulsed power, explosively driven pulsed power, or controlled fusion experiments. There are a limited number of diagnostics that can be used to accurately measure currents at these levels. The most common are calibrated inductive field sensors which are very susceptible to undesirable field coupling and EMI.

Faraday Rotation Diagnostics (FRDs) rely on magneto-optical rather than inductive phenomena and are largely immune to EMI. The polarization of the light in a magneto-optical material is rotated due to a circular birefringence. This rotation is directly proportional to the magnetic field strength and the length over which the magnetic field and optical field interact in the material. FRDs have been used as a method of measuring large pulsed currents for more than 40 years and are presently used at other institutions in a range of high-value pulsed power experiments. A FRD of proven configuration was successfully installed in LLNL's Pulsed Power Lab (PPL) and used to measure current on the ALE3D coaxial load experiment.

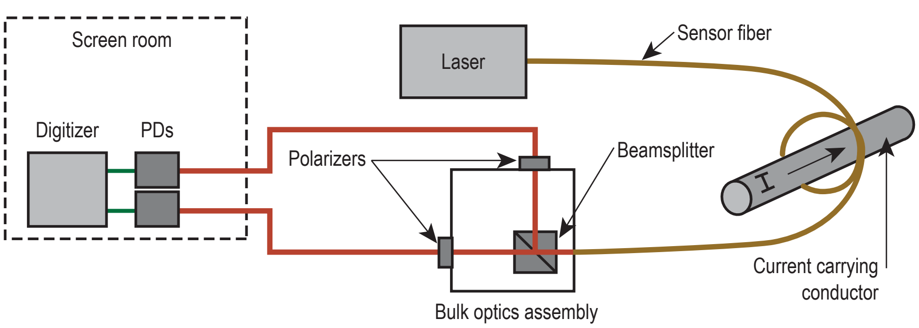

Figure 1. Block diagram of the FRD system.

Project Goals

Our goal for FY2007 was to install and operate a FRD in the PPL high-current test cell, and to acquire the capabilities and knowledge base to support all aspects of FRD implementation, including sensor fabrication, experimental installation and operation, and data analysis.

Relevance to LLNL Mission

FRD sensors have excellent linearity and bandwidth characteristics, and are optically isolated. These qualities make FRDs particularly well suited for application in experiments that involve large quantities of guided or radiated electromagnetic energy. Since failure modes of FRDs differ from those of conventional inductive field sensors, FRDs offer a level of data redundancy for high-value single-shot experiments that is not easily achievable otherwise. Numerous programs at LLNL stand to benefit from this expertise, including explosive pulsed power for high energy density physics research, EM launcher/shaker experiments for military applications, and operations at the NIF.

FY2007 Accomplishments and Results

FRD hardware was acquired and installed in the PPL high-current test cell on the ALE3D coaxial load testbed. A graphical depiction of this system is shown in Fig. 1. A diode laser launches a few mW of linearly polarized light at 850 nm into a FRD sensor fiber, which is a single-mode fiber that is wrapped 50 to 100 times around the coaxial load input (Fig. 2). The magnetic field in the vicinity of the sensor fiber induces Faraday rotation of the linearly polarized

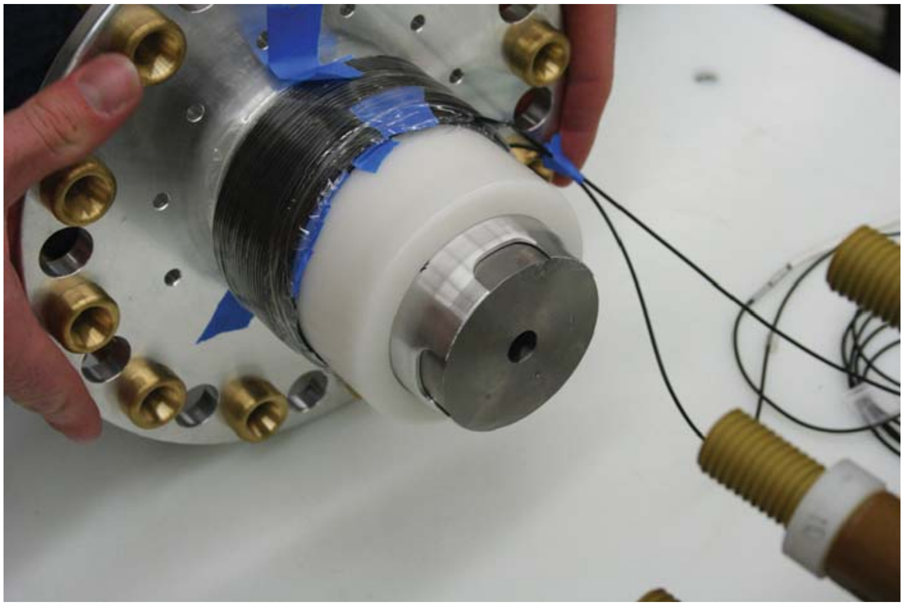

Figure 2. FRD sensor fiber installed on the ALE3D coaxial load testbed.

light. The polarization-rotated signal is coupled into a bulk optics assembly that splits the beam via a non-polarizing beam splitter and passes each beam through polarizers that are at a known relative angle. Both signals are then coupled through multimode fiber onto photodetectors and a digitizer in the screen room.

We have implemented the FRD on four shots of the ALE3D coaxial load validation test. An example of raw data representing the two components of the polarized signal is shown in Fig. 3.

The total Faraday rotation is extracted from the digitized data and is scaled by material constants and geometric factors to yield current. We have created an algorithm that automates this process. A time history of current obtained using this process is shown in Fig. 4, where it is compared to integrated Rogowski coil data. These data demonstrate excellent agreement, within 1% at peak current.

Related References

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2. Day, G. W., and A. H. Rose, "Faraday Effect Sensors: The State of the Art," *Proc. SPIE*, **985**, pp. 138–150, September 1988.
3. Bland, S. N., D. J. Ampleford, S. C. Bott, A. Guite, G. N. Hall, S. M. Hardy, S. V. Lebedev, P. Shardlow, A. Harvey-Thompson, F. Suzuki, and K. H. Kwek, "Use of Faraday Probing to Estimate Current Distribution in Wire Array Z Pinches," *Rev. Sci. Instrum.*, **77**, 10E, p. 315, 2006.

FY2008 Proposed Work

We will continue working on a FRD at 635 nm that will provide improved sensitivity and noise characteristics over the present implementation. Motivating this wavelength change is the fact that the sensitivity of the device varies with the inverse of wavelength squared. The system will be deployable in support of pulsed power experiments at LLNL, NTS, LANL and Site 300. We will continue to work on ancillary aspects of FRD implementation such as sensor fabrication, modeling, and data analysis that permit improvement of the precision and accuracy of the diagnostic.

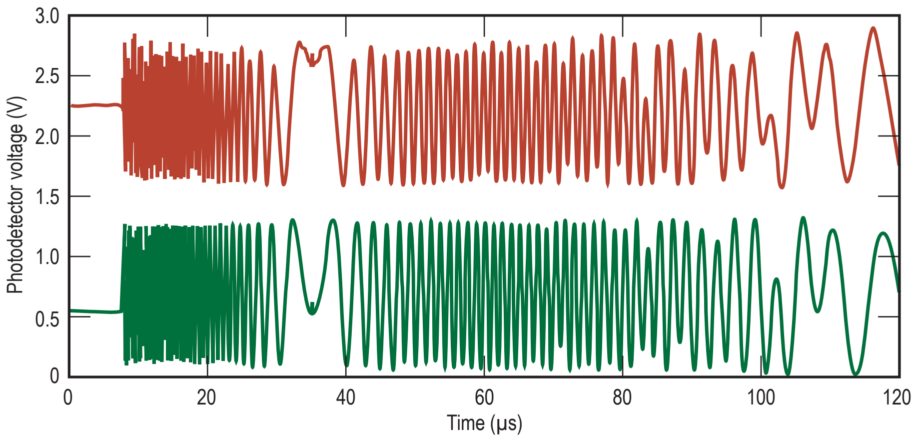

Figure 3. Raw FRD data representing two components of the Faraday-rotated polarized light.

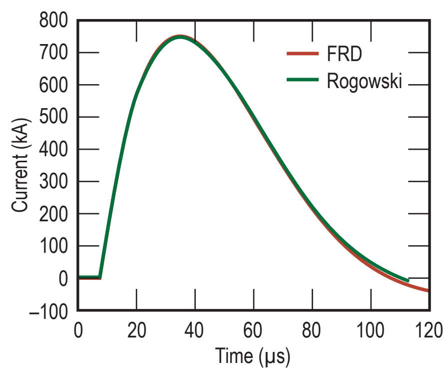

Figure 4. FRD and Rogowski measurements of a large amplitude, time varying current.